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TEACHING TIPS

Experiential Learning: Exploring Nuances When Making Ethical Decisions in a Capstone Design Course

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Abstract

Biomedical engineering capstone design courses provide a salient opportunity to discuss ethical considerations in engineering. As technology and society develop and change, new challenges constantly arise related to how society and technology inform each other. In this space, ethical training for engineering students is critically important for future practicing engineers who may face significant once-in-a-career ethical challenges as well as the smaller compounding daily decisions that impact biomedical research and device design. In this context, topics of social justice as well as bias and inclusion in data and design are particularly important for biomedical engineers to understand the given the human-centered approach to engineering practice. To engage biomedical engineering students in discussion and practice of these concepts, we present a capstone course module to teach traditional ethics studies while exposing students to cases of bias in design in modern technologies including AI, sensors, and devices. This curriculum engages students in discussion of these topics facilitated by biotechnology case studies. All together, we see the curriculum presented here as a response to the need for biomedical engineers to understand the human-centered data in ethical decision-making as well as to meet the desires of students to put engineering in the context of human-centered design and social justice.

Keywords Ethics · Inclusion · Capstone · Design courses

Challenge Statement

Capstone design courses provide a salient opportunity to discuss ethical considerations in engineering. Classic ethics case studies, such as the Challenger [1] or Ford Pinto [2] cases, provide a rich historical context for challenges that engineers have faced and the impacts of their decisions. However, the ethical challenges faced daily by many practicing biomedical engineers can be more nuanced. Additionally, as technology and society develop and change, there are new challenges that engineers are facing related to how society and technology inform each other. Specifically, we see topics of social justice as well as bias and inclusion in data and design particularly important for biomedical engineers to understand.

Biomedical and bioengineering disciplines are relatively new and evolving compared to other traditional disciplines. Codes of ethics have long been the basis for ethics discussions in traditional engineering education [3]. Previous work recognizes the challenges to teaching ethics to bioengineering students who learn and work in a highly interdisciplinary field with close ties to living end users and often open-ended problems [4]. The interdisciplinary Ethics Across the Curriculum program is being explored at a variety of higher education institutions [5]. In biomedical engineering, an adaptive approach to teaching stem cell ethics [6, 7] was shown to increase student considerations of stakeholders in ethics education and is believed to provide tools for students to navigate ethics within this rapidly evolving discipline. In another study, incorporating ethics in a tissue culture laboratory course provided students with opportunities to reflect on emotions during animal work and left students with a greater understanding of ethical concerns and empathy related to animal use in biomedical engineering [8].

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While some curricula focus on global health issues [9], most biomedical engineering ethics curricula documented in literature focus on ethics of animal use [8]. We believe that there is a need for a human-centered approach to ethics given the rapidly evolving use of AI and data in biomedical engineering devices and technologies directly impacting human health [10]. Design frameworks such as Stanford's Biodesign program [11, 12] and the related Value Sensitive Design [13, 14] have provided a structure for biomedical engineers to consider a variety of users and their interactions with medical products and technologies in development. A summary of 2019 meeting of Fourth BME Education Summit held at Case Western Reserve University in Cleveland, Ohio, highlighted a need to expose biomedical and bioengineering undergraduate students to data science as a way to make sense of disparate and sparse biological data [15]. This group also recognized that data science in BME is lacking a code of ethics and suggested some groups to develop that code. In the absence of a standardized method to teach ethics in the evolving BME landscape, more empirical work is necessary to fully explore the effective methods to teach the nuances of ethics in biomedical engineering.

Novel Initiative

In this curriculum development project, we integrated a module of inclusive design and ethics case studies to allow students the space to (1) practice recognizing ethical issues, (2) understand the total impact of engineering work on individuals in society, (3) broaden the definition of their end users in design projects, and (4) practice decision-making in complex and nuanced situations. Through this course module, we aim to prepare biomedical engineering students for the workforce, where they will face small yet compounding challenges regularly. We aim to do this by equipping students with knowledge to be advocates for social justice change through bioengineering practice. To do this, we developed a module to teach traditional ethics studies while exposing students to cases of bias in design in modern technologies including AI, sensors, and devices. Next, we engage students in discussion of these topics facilitated by biotechnology case studies. This module was developed for a unique capstone design offering [16], which integrates a masters level project management capstone course with senior design in a bioengineering department. This unique setting further allows for near peer mentoring through these conversations.

Students in this capstone course, may have had prior ethics education. Because the course includes masters of engineering (MEng) level students, prior ethics education varies. Students in our MEng program come from science, technology, and engineering programs globally. Their ethics education will align with the institution in which they earned a bachelor of science degree. Undergraduates in the course, typically in their fourth year of the Bioengineering curriculum, are first exposed to ethics education in first-year, required courses. The modules taught in first-year Bioengineering courses focus on traditional ethics case studies, ethical use of animals and human subjects in research, as well as ethical considerations when using pulse oximeters, a device that is evaluated in the first-year course [10]. The prior ethical training that students bring to this course allows for diversity of thought and perspective in course discussions as well as opportunities for peer mentorship across the programs involved.

In this teaching tips article, we will describe the implementation of our inclusive design-ethics module in an integrated masters and bachelors level design course. Our curriculum builds upon previous efforts to create inclusive classroom spaces [17] and include social justice topics in bioengineering courses [18]. Course and program evaluations over three years of delivering the curriculum provide evidence that students appreciate faculty effort to discuss issues of social justice in classes. Case studies provide a framework to facilitate class discussion and have strengthened cross-program teams. Our goal is to provide curriculum materials and insights to other instructors in biomedical engineering education to update current curricula to reflect the changing society in which we practice and meet the needs of students who are eager to put engineering within a social justice context.

Lecture: Inclusion and Bias in Design

The module presented here was piloted within a bioengineering design course. In our context, students were situated on teams and assigned a semester-long design project. At the point in the semester that this module was delivered, students had been engaged in the engineering design cycle that includes needs assessment, stakeholder interviews, and prototyping iterations. The module opens with a lecture presented to students that includes many points for student engagement. This lecture begins with an instructor guided reflection asking students to "*envision your end user*." Students are then prompted to reflect on their perceived end user with the following questions:

1. *Does that person look like you?*
2. *Does that person look like a majority identity holder in engineering?*
3. *Does who you visualized represent a diversity of people?*
4. *How might the design be used differently if your end user was different?*

Understanding that students may or may not have the capacity to reflect deeply on these ideas, we use this

reflection exercise as an initial exposure to these ideas. Students are not required to share answers, simply reflect individually on these concepts.

We discuss implicit bias, how it is pervasive in healthcare [19] and how a lack of diversity in the engineering discipline [20] can result in entire groups of people being excluded in engineering design. The objective of the lecture is to encourage students to expand their thinking of end user groups and empower them to approach engineering design through a more inclusive lens than has historically been practiced. We build upon the reflection to present journal articles, books, and codes that examine how specific groups have historically been excluded from design decisions and the impacts of those decisions. Lecture slides are shared in Supplemental Materials and topics explored summarized in Table 1. The list of topics is not exhaustive yet aims to address inclusion and bias across a variety of identities.

Practice: In Class Case Study Activity

Along with highlighting and discussing critical and important ethical issues, it is important for our students to practice ethical analysis by working through a case study. As a component of the module, students work in teams to discuss a case study and to analyze the ethical issues described in the case. The source of the cases used in the course is the Markkula Center for Applied Ethics at Santa Clara University. These are short cases that require critical thinking and problem solving within the context of ethical decision-making. One case used in this module that addresses biological data, data science, and design is entitled: "Questioning the Average." The case is reprinted with permission of the Markkula Center for Applied Ethics, www.scu.edu/ethics:

Questioning the Average

Willow's company has been contracted to oversee data management for a clinical trial. The trial is being conducted on a newly developed drug and consists of applying the drug on the subject's skin and monitoring the effects the drug has. This trial is in the first phase of testing, meaning the goal of the trial to determine if the drug is safe for human use.

The drug is applied topically and the rate at which the drug is absorbed into the subject's skin is monitored. After data had been collected from all the subjects participating in the trial, Willow analyzed the data and found that there was a wide range in the rate at which the drug was absorbed. All subjects were given the same dosage amount, and it was expected that the drug would be absorbed at a slow, constant rate. Some subjects showed this trend, while others absorbed the drug at a high rate, meaning a high concentration of the drug quickly entered their system. This was cause for concern because absorbing the drug at a high rate could lead to serious health consequences for the potential users of the drug.

Willow reported her findings to her client, the company which had developed the drug. Her report outlined the wide range in rate at which the drug was absorbed. The client was unsatisfied with the report and asked Willow to re-analyze the data. However, this time they requested a report which contained only the average rate at which the drug is absorbed. Willow knows that a report which only presents the average rate of absorption will not show all the safety concerns shown in the clinical trial data. However, her client assures her that her report will only be used to show investors that the drug has progressed to clinical trials. Additionally, the company assures her that they are fully aware of the safety concerns associated with

Table 1 Examples of inclusion or bias in engineering design from literature

Topic	Summary
Accessibility	• 2010 Americans with Disabilities Act (ADA) Standards for Accessible Design updates regulations with regard to hospital design [21] • WCAG guidelines inform design of accessible websites and apps [22]
Race and Ethnicity	• Optical oximetry impacted by skin pigmentation resulting in racial bias in oxygen saturation measurements [23, 24] • Disparities in intersectional accuracy in facial recognition software [25, 26]
Gender and Sex	• Heart attack symptoms differ for men and women, medical training has historically not included both [27] • Crash tests are modeled after the average male body [27] • Cis-normative training data used in training Transportation Administration airport scanners [28] • Cell sex impacts response to pharmaceutical interventions [29] • Editorial mandates to report gender and sex in research studies [30]

Table 2 Establishing engineering and technical issues based on questioning the average case (Example)

Engineering/Technical Issue(s) *(Evaluated and debated in groups)*
• Applying the drug on the subject's skin and monitoring effects of the drug
• Expected that the drug would absorb at a slow and constant rate—widely varying absorption rates among the subjects.
• The goal of this first phase of testing is to determine if the drug is safe for human use.

Table 3 Establishing ethical issues based on questioning the average case (Example)

Ethical Issue(s) *(Evaluated and debated in groups)*
• Client unsatisfied with report showing range in rates, wants only averages
• Showing the average rate of absorption will not show all the safety concerns for the clinical trial
• High absorption rates could lead to serious health consequences
• Aligning data results for investor presentation

the drug and are currently researching methods to fix these problems.

What Should Willow do?

Researchers argue that most university-based ethical instructions for engineers run the risk of being only trivial [31]. Problems may be assumed to be binary: right or wrong. In reality, students will face problems that are multi-faceted where scientific, technological, and social issues are interdependent and difficult to parse [27, 28]. For example, in this case presented above, patient demographic data are never discussed. How patient demographic data across a variety of identities impacts this data may lead to groups of individuals benefiting or being harmed by this drug candidate. It is important that students be exposed to a structured approach to reason through these ethical issues [32]. As a component of the ethics module, we introduce a framework for students to use as they consider the ethical dilemma in the case and work toward a decision [33].

It is critical that the case examples demonstrate both technical engineering and ethical issues. Students should engage both issues simultaneously, creating a context where they can recognize some of the limitations of technology, the limits of our ability to recognize all the potential unintended consequences, and the limits of our ability to always discern unique cultural differences.

The case analysis framework [33] focuses on:

- Identifying the engineering/technical issue(s) (Table 2)
- Identifying the ethical issue(s) (Table 3)
- Identifying the critical stakeholders (Table 4)
- Assessing objectives of the stakeholders (Table 4)
- Understanding the impact of decisions on the stakeholders (type of impact and level) (Table 4)
- Proposing course of action for both the engineering/technical issue(s) and the ethical issue(s)

Table 4 Stakeholder analysis based on questioning the average case (Example)

Stakeholder	Objectives	Impact score
Willow	*Example objectives* • Conduct accurate and quality testing and analysis • Stand behind signing off on findings • Keep co-workers employed	*Students individually assign a score that represents the impact of each stakeholder's role in the case. Then evaluate and debated in groups.* *1—2—3—4—5*
Willow's Company	• Fulfill contract • Satisfy client • Maintain reputation • Keep company operating	
Drug Company	• Validate third party drug trials • Successfully pass all required testing • Satisfy investors (more investment)	
Government	• Regulate pharma industry • Penalize failure to comply • Protect public safety, health and welfare	
Consumer	• Use a safe and effective drug • Inclusive design	

Students are given time in class to read, discuss, and evaluate cases. Each Table below represents a stage in the case analysis and whole group discussion occurs after each analysis is completed by student teams.

This framework provides a mechanism for students to evaluate ethical situations in a more comprehensive way, moving away from the binary—right or wrong decisions. Our expectation is that students leave this course module with an understanding that as engineers they have the responsibility to ask tough questions, to think about a diversity of end users, and to ensure that all stakeholders voices are heard and respected throughout the engineering design and implementation process. Having this understanding is critical, because these engineering decisions can have a significant impact on the outcome of others.

Implementation in Design Project Assignments

After completing this module, students are tasked with expanding upon the case study to apply this framework to their own semester-long design projects. Students complete a written report throughout the semester documenting their design process. We task students with writing about their experience exploring end user groups, inclusive design practices, and the concept of "questioning the average" to their design project. We ask students to call out specific engineering ethics codes, how they apply to their project, and how they can be expanded upon through the lens of social justice and inclusive design.

Reflection

The composition of the curriculum, the topics we incorporate into courses, and the way in which we choose to teach them are ways in which we signal to students what is important in the biomedical engineering discipline. To bring in ethical considerations early into the engineering design process suggests a re-thinking of the idea of "doing no harm" to "doing the most good." We ask students to create design solutions that are not only technically sound but are inclusive regarding overall benefit and impact. We see this curriculum as an opportunity to engage students in reflecting on how engineering design does or does not address the needs of a variety of end users and the ethical considerations of those designs. This addresses challenges of teaching biomedical ethics case studies previously described as "abstract" when compared to students' lived experiences [34]. A majority of our students are able to directly reflect on experiences of using facial recognition software, walking through an airport scanner, taking medication, or riding in a car. This allows students to internalize the aspects of inclusion and exclusion that dictate how these technologies are designed and used.

This curriculum is, for some students, the first time they are discussing social justice topics in a technical engineering course. Overall students have appreciated the inclusion of these topics as evidenced by three years of course evaluations in which students often bring up this lecture. One student stated, "*I really appreciated the presentation on bias in the engineering field. Too often this kinda stuff is just swept under the rug, so it was nice to have a candid conversation about it in class.*"

Over 3 years of implementation, we have iteratively developed the curriculum based on instructor and student feedback. Most recently, we added case studies to provide an opportunity for students to discuss with peers in class these topics, especially if they don't feel comfortable volunteering thoughts in a larger class setting. The case study provides a smaller group of peers (undergraduate) and near peer mentors (MEng students) to facilitate discussion in a structured analysis framework. This class activity supports students in understanding how to apply the framework and has resulted in richer application of the concepts in their own projects.

Evaluating the outcomes of this curriculum, on students' ethical thinking and approach to engineering design, is an important next step. Others have reported methods used to understand learning and application of ethical principles in biomedical engineering settings. Martin et al evaluated the undergraduate factual understanding and adaptive application of ethics principles[6] which can be useful in understanding the differences between our in class activity and the broader application of ethical decision-making in team-based projects that come from a variety of areas within the biomedical engineering discipline. Goldin et al. evaluated validity and reliability of an Assessment Instrument on measuring higher level moral reasoning skills operationalized during modules of biomedical engineering ethics [4]. Again this tool may be useful in understanding how our students reason across stakeholder groups to come to an ethical decision consensus. Lastly, the ethical becoming and empathy in engineering ethics theoretical frameworks have been used by Hess et al. in a mixed methods study (quantitative survey, written reflections, and focus group observations) [8]. This work was performed in the context of animal studies, common in biomedical research. We hypothesize that the intersection of empathy in engineering will be enhanced by our use of social justice as a lens through which to explore ethical concepts. The study design presented by Hess and colleagues will help us to explore that hypothesis.

Evaluation

Over the three years of developing this curriculum, course instructors regularly met to review aspects of the curriculum

and how it may be improved each semester. The following section details the stages of development and application of a continuous improvement model adopted by instructors.

Lecture Content to Support Assignments

- Students have included discussion of ethics in capstone reports since the program and course were developed (10+ years ago). Instructors find that the associated lecture helps support students in this effort and sets expectations for application of classic ethics cases or more nuanced decision-making to team projects. Instructors have observed more and more students applying social justice consideration to their projects since the development of this module.
- As the field of biomedical engineering is rapidly evolving, lecture slides are updated each semester with examples from the latest literature or news articles.
- Instructors design lectures to provide examples relevant to each capstone team. For example, for teams developing a web-based app, accessibility standards and case are presented in class. Instructors have decided to be intentional about consistently updating lecture to have content that each team can relate to.

Inclusion of Cases and in Class Discussion

- To scaffold the process of applying ethical frameworks and decision-making to team-based projects, instructors added cases from the Markkula Center for Applied Ethics at Santa Clara University to this ethics module in year two of its development. Cases provide an opportunity for students to practice application of the ethical decision-making framework. Instructors can also guide discussions and provide support.
- Students conduct case studies in groups that may not include their capstone team. This allows for cross pollination of ideas and thinking toward students' independent projects.
- Students' judgment of the case may be influenced by the context in which they are presented the case. Instructors would like to test this hypothesis by presenting the case without the context of an ethics module to understand if student approaches to decision-making change in this context in a capstone design course intended for students to apply all engineering skills to new problems.

Assessment of Student Identity Development

To understand the impact of this curriculum on students' empathy, ethical and engineering development, instructors plan to use a mix methods study design to answer the research question, "*How does a capstone curriculum on human-centered ethical decision-making influence student development at the intersection of empathy and engineering identity?*" To test our hypothesis that human-centered ethical considerations may further enhance empathy development when compared to animal-centered cases, we will use the empathy in engineering ethics [35] and ethical becoming [36] frameworks as a lens through which to view data from an Institutional Review Board approved study. Leveraging the previously cited study design [8], a quantitative survey will include the empathic concern and perspective-taking constructs from the Interpersonal Reactivity Index [37]. The survey will also include engineering identity measure items [38] which are also administered to students in first-year Bioengineering course at the institution of study. Items such as "*I find fulfillment in doing engineering*" and "*Others ask me for help in this subject*" can be explored further in individual interviews with students after completing the capstone course. The goal of interviews will be to qualitatively understand the intersections of ethical becoming and engineering identity development in the context of exploring and applying an ethical framing to capstone projects. Lastly, data will be collected from student assignments and written reflections that will categorize ethical approaches, application of the module to team-based design projects and demographic information to understand the ways in which students from varying identity groups may benefit, engage in, or reject the curriculum differently.

With the goal of developing the curriculum to increase inclusivity in education and practice of biomedical engineering, student-focused data will enable further development of the curriculum with this goal in mind. All together, we see the curriculum presented here as both a response to the cited need for biomedical engineers to understand the use of sparse and human-centered data in ethical decision-making [15] as well as to meet the desires of students to put engineering in the context of human-centered design and social justice.

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Data Availability Materials are available as Supplemental Information or by request from the authors

Code Availability N/A.

Declarations

Conflict of interest The authors declare no competing interests.

Ethical Approval Data presented in this paper are considered Not Human Subjects Research by the University of Illinois at Urbana-Champaign Institutional Review Board (NHSR Protocol #23380)

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